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SATELLITE PAYLOAD DATA COMMUNICATIONS
AND PROCESSING TECHNIQUES

BACKGROUND OF THE INVENTION

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This invention relates to satellite communication systems, and more specifically relates to such systems in which satellite data is processed by an earth processing center.

Satellite communications are taking on increased importance as evidenced by the following patents issued in the name of one of the inventors of the present invention: U.S. Patent 5,867,530, entitled "Method and Apparatus for Accommodating Signal Blockage in Satellite Mobile Radio Systems," issued in the name of Keith R. Jenkin, on February 2, 1999 and U.S. Patent 5,940,444, entitled "DARS PSF With No Data Rate Increase," issued in the name of Keith R. Jenkin and Stephen J. Toner on August 17, 1999.

Prior satellite communication systems requiring earth processing centers including, for example, weather satellite

systems. In such a system, one or more traditional ground stations are used. The weather satellite collects data continuously and saves it onboard, and then "dumps" that data as it over flies a traditional ground station. Polar locations are chosen as sites for traditional polar orbiting missions since the poles are overflown on every orbit, thus minimizing the number of traditional ground stations needed. (If the stations were located elsewhere, say near the equator, a prohibitively large number of these expensive facilities and sustaining staff ringing the globe would be needed to avoid blind orbits.)

Significant Data Timeliness Compromise

Mission data is continuously collected and stored onboard until a traditional ground station is encountered. This results in data already being delayed by up to as much as approximately 100 minutes before it even reaches the ground, which for weather data is highly undesirable.

Traditional Ground Station Complexity and Cost

Since there are very few downlink opportunities, and each of them is usually critical to prevent blind orbits, the stations must have extremely reliable communications with the satellite to avoid unacceptable performance.

Usually a bi-directional system is used (both downlink and

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uplink) to first establish a valid link, then command the satellite to begin the downlink process. Data integrity can be checked in near real time on the ground, and handshaking schemes can instigate the retransmission of data packets in more sophisticated systems. A full time (24-7) crew is essential at traditional ground stations for rapid repairs if needed, and also man-in-the-loop scheduling conditions automated systems can't handle (i.e. preemption situations). In remote regions the continuous staffing required over many years becomes a major consideration in program life cycle cost. In a case like McMurdo (Antarctica) the environment is incredibly adverse, and logistics become a major concern. While adding the example McMurdo is attractive since the nominal maximum onboard storage time is reduced to half an orbit instead of one orbit, the programmatic impact is substantial.

Minimum Pass Limitation Of Prior Systems

Since a downlink to a traditional ground station is a complex operation, a practical limit on the geometrically available contact time is usually imposed. The ground station antenna (which might service several other satellites too) needs to be slewed, signal acquisition accomplished, and reliable communications need to be

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Since the traditional ground stations are generally located in remote, sparsely populated areas, taking advantage of commercially financed, installed, and maintained fiber optic networks is unlikely since there is no financial motivation for servicing such geographic (polar) areas. This means communication from traditional ground stations to the processing center (probably in the U.S.) is expensive for the data rates (bandwidth) needed by future weather satellites. Either dedicated, sole-user fiber is needed, or perhaps a complex, risky, and expensive "hop"

from the station to a communications satellite and back to the U.S. is needed. Or, a slow existing link might be used, but because of limited bandwidth, data will again be delayed awaiting it's turn in a rate buffer queue for ground communication.

Frailty Of Prior Systems

Since there are, practically speaking, several single point failure opportunities in a traditional ground station system, each point must have incredibly high (i.e. expensive) reliability and sufficient availability. For instance, if a key station is down for a prolonged period, say due to earthquake damage, or immediately irreparable equipment failure, or staffing problems and so on, critical data will be lost or arrive so late it's essentially useless.

Spacecraft Complexity/Risk Of Prior Systems

Since passage over a traditional ground station is on the order of 10 minutes, and the stored data is from a nominal 100 minute orbit, high downlink data rates (a minimum of 10x payload data rate) need a spacecraft pointable, high gain antenna to keep spacecraft electrical power and transmitter needs reasonable. This means either

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BRIEF SUMMARY OF THE INVENTION

The preferred embodiment is useful in a satellite communication system comprising at least a first satellite

arranged to receive first data from a first source and second data from a second source displaced from the first source to receive control data and to transmit the first data and the second data to the earth. In such an environment, the first and second data may be processed by receiving the first and second data at the earth from the satellite. According to an apparatus embodiment, a first receptor terminal is arranged to receive the first data and a second receptor terminal is arranged to receive the second data. The first and second data are transmitted to a location adjacent the earth for processing. In the apparatus embodiment, the transmitting is achieved by a wide band network. The first data and second data are processed at the earth. In the apparatus embodiment, the processing is achieved by a processing center. By using the foregoing techniques, the first and second data may be processed with increased speed and at reduced cost.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of a preferred form of communication system employing communication satellites and embodying the invention.

Figure 2 is an enlarged view of one of the satellites shown in Figure 1.

Figure 3 is a schematic block diagram of a preferred form of receptor terminal made in accordance with the invention.

Figure 4 is a schematic block diagram illustrating a preferred form of data recovery in the event of an anomaly in the system shown in Figure 1.

Figure 5 is a schematic block diagram of a portion of a preferred form of processing center employing a plurality of computers.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Glossary of Terms Used in this Specification

"Autonomous Mode" An alternative embodiment where the system is completely autonomous, yet with coverage immunity to failures. Improvements and repairs still can be made on the ground only.

"Traditional Ground Stations" In the context of this specification, this refers to large, complex, expensive, facilities used for many years in the past to support communications with various satellite systems.

"Receptor" The preferred embodiment may use, for example, a distributed network of small extremely simple, and relatively inexpensive, unmanned antenna/receivers that

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are receive-only. (Downlink signal reception, but no uplink signals sent to the satellite(s)). These are technically earth stations, but of a significantly reduced complexity/cost class than the Traditional Ground Stations
5 noted above.

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10 "Checksum" This is one of several mathematical means of verifying the integrity of a block of digital data, of varying potency. For simplicity in describing the preferred embodiment, checksum will be referred to, but any of the several other, possibly more complex and robust methods may be used for a specific application. A checksum is simply the sum of all values in a known-size dataset. If a subsequent checksum is done on the same dataset at a later time (say, after communication transmission) and it's checksum value
15 isn't precisely the same as the original checksum for the same dataset, errors in the dataset are present. Checksum does not allow correction of errors, but merely is a test (only) for data integrity. The important point is that the amount of bits needed for a checksum value (or other
20 integrity-test-only method) is extremely small compared to the amount of bits in the dataset itself.

"Virtual Spherical Coverage" A feature whereby the whole earth can be mapped in a timely and confident (high data

integrity) manner, despite having intermittent communication contact (satellite-to-ground downlinking) of less than four PI steradians (spherical coverage).

5 "Mission Data" The actual useful information from a satellite, such as imagery produced from mission instruments, plus any overhead needed such as headers and encryption. (Other data from a satellite typically includes things such as satellite housekeeping information, which is typically very low data rate in comparison to the actual end-use mission data.)

10 "Data Timeliness" The time from when data was collected, to when it becomes useful to the end-user. In systems such as the example mission cited below when configured as a legacy system using traditional ground stations, the dominant
15 timeliness constituent is the delay between downlink contacts from the physical constraints of orbit and ground station geometries. Also referred to as data aging or data latency.

20 "Preemption" For one of several possible reasons, a geometrically possible communication opportunity (satellite is within nominal communication range and adequate other conditions) is not utilized for downlinking mission data. Examples of preemption include: 1) ground station is

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LEO: Low Earth Orbit (in the hundreds of kilometers altitude range).

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MEO: Medium Earth Orbit (in the thousands of kilometers altitude range).

GEO: Geosynchronous Earth Orbit (an altitude of around 36,000 kilometers, if circular, resulting in the satellite
5 having an orbital period the same as Earth's rotation (one day), causing it to appear stationary overhead to an observer at a fixed location on Earth.)

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10 "Sun-Synchronous-Polar-Orbit" At certain circular orbit altitudes and associated inclinations (e.g. around 800 Km and a few degrees of inclination) a satellite's orbit plane follows the Sun-Earth annual cyclic vector angular motion in inertial space. Such an orbit is advantageous to missions, such as the weather satellite mission. This orbit results in the entire Earth being mapped in a relatively short time
15 at desirable constant sun illumination angles, owing to the combined dynamic geometry of the Earth's daily rotation, plus orbital motion, plus the cross-track swath of the satellite sensor's field-of-view. For global weather observation from relatively low altitudes (e.g. LEO versus
20 GEO), this is an ideal scenario: full spherical coverage from consistent observation angles updated fairly frequently.

"SSR" Solid State Recorder. Recently satellites have been implementing onboard data storage with solid state recorders, in lieu of earlier data storage implementations such as mechanical tape recorders. SSRs are essentially

5 large amounts of RAM (as in a computer) plus some controlling circuitry. Obviously the elimination of moving parts (which eventually wear out and are prone to failure) is a reliability advantage. More importantly for system 10 is the random addressing capability (the "R" in RAM), programmability, and asynchronous operation, as will be shown.

"Code and Coding" Two disparate uses: 1) Code referring to computer program instructions, and 2) Coding referring to data overhead for error detection/correction algorithms.

15 "Satellite Operations Center" Usually a single facility for controlling satellites. Here commands are sent to the satellite to specify it's operation.

"Processing Center" Where mission data arrives to be converted to useful information for the intended end use.

20 For instance, in connection with the preferred embodiment, weather maps are produced by analyzing (via computer) multi-spectral imagery data collected by the satellite with

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algorithms that can convert that raw data to a useful end product format.

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The preferred embodiment is useful for many possible satellite/system configurations of varying characteristics and missions. However, the preferred will be described for purposes of illustration, but not of limitation, in connection with an LEO circular Sun-Synchronous-Polar-Orbit weather mapping satellite system. For this example, timely global mapping is important to mission objectives. (Weather data is highly perishable, since weather conditions are highly dynamic.) Such a weather satellite system may have several sensors (data collection instruments), spanning a large range of the electromagnetic spectrum in observation of weather-related phenomenology below the satellite. Such sensors typically produce a steady stream of mission data, typically of high density (high data rates, such as that needed for multi-spectral imaging).

Referring to Figure 1, the preferred embodiment includes a satellite communication system 10 comprising a weather satellite 20 circling the earth E in an LEO 21. Another identical weather satellite 22 circles the earth E in another LEO (not shown). System 10 also includes a processing center PC and receptor terminals A, B and C which

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pass a minimum of 40 Gigabits per second. In the next couple of years, the entire globe (with the exception of arctic Polar Regions having nil population and commerce) will be a "spider web" of multi-terabit fiber optic cable. This is due to fiber optics technology where many optical spectral bands are used in a single fiber strand to produce nearly a two order of magnitude increase in communication data rates. The preferred embodiment uses this extremely fast and inexpensive communication from it's receptors, such as A, B and C, located most anywhere on earth, back to the Processing Center, PC. The bandwidth proportion needed by a weather satellite system, such as the one shown in Figure 1, is on the order of one-one-hundred-thousandth of the capability of a terabit optical fiber, which is essentially epsilon and therefore very inexpensive. The preferred embodiments also may be used for applications other than a weather satellite system, such as television, HDTV, Internet, telephone (including video soon), videoconferencing, and financial data communications. Thus, the preferred embodiments take advantage of this global inexpensive communications capability financed by commercial/consumer markets, instead of the traditional

method of utilizing mission-dedicated ground communication means.

SSR Programmability and Flexibility

Referring to Figure 2, satellite 20 includes an on-board processor 23, which stores mission data in an SSR 24 that may take the form of a recirculating memory. In the past, satellite data storage methods such as mechanical tape recorders would operate in a mode of continuous recording while out of ground station contact, then high rate playback during a downlink pass, in a fairly rigid sequential modality. SSR 24, on the other hand, can be treated like RAM in computer 23: access to all memory data at any time and in any order is possible, both for recording (writing), and non-destructive and highly selective playback (reads). The preferred embodiment uses these SSR features of random access and non-destructive reading in several ways.

The preferred embodiment uses globally distributed simple and inexpensive "receptors" A, B and C. These preferably are small, unmanned antenna installations located at easy access points to the global fiber optic network.

Referring to Figure 3, exemplary receptor terminal A includes a small dish antenna 40 approximately two to four meters in diameter, an antenna pointing gimbal control unit

44 (e.g. servos and encoders), an appropriate antenna feed
48, a receiver/demodulator 50 which downconverts the carrier
signal received from one of satellites 20 or 22, and
interfacing electronics 60 to the commercial fiber optics
5 network link 34. A phased array antenna could also be used.

Receptor terminal A receives the open-loop broadcast
signal from an over flying satellite, collects the RF signal
the satellite is transmitting, demodulates the signal to a
digital format, adds simple periodic "wrap" tagging headers
10 of time and location and synchronization bit patterns around
an arbitrarily sized "macro packet," and forwards the raw
bit stream via commercial optical fiber link 34 to the
processing center PC. There are no complex data operations
at the receptor, it merely acts as a bridge from the
15 satellite broadcasts to the processing center. No data
analysis or assessment or decisions are made, nor are any
processing operations done by the receptors. They simply
collect data and pass it along. Since the receptors are very
simple and small and located on existing fiber
20 communications channels, their deployment and operation is
very cost effective.

It will be shown that a modest number of receptors is
needed to implement the preferred embodiment because the

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preferred embodiment employs virtual spherical coverage which mitigates the fact that several gaps exist in true geometric coverage opportunities. In the preferred embodiment, 12 receptors are used to achieve reasonable coverage. Depending on the needs of the system, at least twice that many receptors may be deployed.

Still referring to Figure 3, receptor terminal A also includes a GPS antenna 70 and a GPS receiver 72 which can, for example, receive the time of day. A computer with ephemeris tracking software 80 controls gimbal control unit 44 in a well known manner. A mass data storage unit 90 stores mission data in case of problems.

Referring to Figure 4, system 10 includes a satellite or mission operations center 100 comprising an adaptive logic controller 102 which automatically and transparently adapts system 10 to any dynamic operational scenario without compromising data quality or incurring data loss. Controller 102 provides receptor failure mitigation, and automatic system acclimation/adoption of new receptors added to the system. In a sense, the system 10 "learns" as it operates, and continuously, and independently adapts to system configuration changes. In other words, system 10 provides a practical virtual spherical coverage system with

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data integrity and minimal, if any, data loss. System 10 also provides near real time data collection to data delivery time, a robust and forgiving mode of operation, a life cycle cost advantage, easy growth and expandability.

5 System 10 also provides nearly continuous downlink coverage for LEO and MEO satellites.

Referring again to Figures 1 and 2, satellites 20 and 22 comprise conventional LEO satellites consisting of the usual, normal subsystems for providing power, attitude

10 control, orbit maintenance, a benign thermal environment, and command/status communication, etc. The satellites also include sensors 27 and 28 for gathering weather data.

The satellite mission data collection subsystem for satellite 20 comprises medium data rate (say 4x sensor data

15 rate) data downlink equipment 25 including programmable SSR 24 (random access), conventional data multiplexing, coding, and encryption functions, and a fixed, wide field of coverage broadcast antenna.

The function of this medium data rate satellite

20 downlink communicating subsystem is to transmit mission data continuously, and to store it for short periods during communication gaps and transmit it along with real time mission data at the next receptor encounter. This

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broadcasting on cue is metered by periodically updated, preloaded commands and a frequently updated onboard stored digital contact zone reference map.

Referring still to Figure 1, system 10 includes simple
5 low cost, modest reliability, unmanned receive-only
terminals A-C located at generally equally globally
distributed convenient sites. The receptors are in
reasonable proximity to the worldwide network of fiber optic
communication channels 32, 34 and 36 for fast and cheap
10 passage of received mission data to a common mission
Processing Center PC. The receptors can, for example, be
mounted on the rooftops of existing facilities, including
government embassies (U.S. and or friendly countries),
commercial global communications provider's facilities (e.g.
15 MCI or AT&T), military installations, suitable traditional
ground station sites, or any of several global satellite
command and control facilities. Anywhere cheap fiber optics
communication is available. Note that if a location
critically needs a receptor for ultimate mission data
20 timeliness in that locale but fiber communication isn't
within practical reach, a "bounce" to a convenient comsat
could be set up with existing available equipment, or
perhaps a microwave or coaxial cable, or a conventional

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communications link (e.g. T1) to the closest fiber optic network interface. A receptor could be installed on military or commercial ships having adequate communication links, with five-space motion backed out of pointing commands.

Still referring to Figure 1, system 10 includes a traditional satellite operation center 100 for sending operating commands to satellites 20 and 22. In system 10, center 100 is identical to a traditional command center and operation, except that SSR and medium data rate transmission commands and onboard maps are included in the command stream, which are prepared from system health information gleaned from mission data reception at the processing center PC.

Referring to Figure 1, the PC provides a facility where all mission data from the satellite(s) arrives to be analyzed and formatted for end use by specialized science-based algorithms, a common function of weather systems. At the PC, data integrity is continuously tested ("checksums" and/or one-on-one redundant data duplicates compared from circuitous routes) and any necessary system reconfiguration commands forwarded to the satellite 20 and 22. Note that these are very low data rate and occasional commands that

can be sent through a variety of existing channels, such as SOC 100, a data transmission satellite (e.g. TDRS), a traditional ground station, or any of many distributed satellite command facilities. Note that the processing center PC and operations center 100 may reside in one and the same physical (shared) facility, in a convenient location such as a city in the continental U.S.

Referring to Figure 1, Mission Data collection is achieved in a conventional manner by satellites 20 and 22. Sensors 27 and 28 continuously observe the Earth and it's atmosphere producing a continuous stream of data. Onboard electronics then condition the data, multiplexing various data sources, compressing, encrypting, and other common data formatting operations. (As noted above, the data rate for convenient illustration here is assumed at a constant rate, but could also be variable.)

In satellite 20, data is routed to two destinations: the first to the SSR 24 (Figure 2) for continuous onboard storage, and the second to a multiplexer at the medium data rate broadcast downlink transmitter. At the multiplexer it is always continually broadcast in real time as data is collected. At the SSR destination it is also always continuously stored incrementally in time (sequence).

SSR 24 (Figure 2) can be configured as a "ring buffer."
This is a logical memory arrangement where data is
continuously written at the "head" pointer as it
continuously advances around the (virtual) "ring." The size
5 of the ring is such that several orbits of mission data are
stored at any time (e.g. five orbits). As the head pointer
advances, it will eventually catch the "tail" pointer and
begin overwriting the data that is (in this example) five
orbits old. At any instant, all data from a time exactly
10 five orbits worth prior is stored, and instantly randomly
accessible.

In the satellite 20 ring buffer implementation, data is
never released, but only gets finally overwritten as the
head chases the tail of five orbits prior. Thus, data is
15 always available for delayed transmission (when a contact
gap exists) or when data that was assumed successfully
received is not, as reported/requested in later
(asynchronous) uplink commands/reception status from the
operations center, and retransmission of poor quality
20 (noisy) or missing data is needed.

sub 25 } So, system 10 asserts that it's anticipated
transmissions to expected active contacts will be
successfully received by receptors, such as A-C, and

forwards the transmissions to processing center PC, open loop, according to it's onboard contact availability map. When a gap in coverage is indicated by the map, that data (being continuously stored in the ring buffer 24) is marked

5 for later transmittal, is retrieved from the SSR 24 and is multiplexed along with the continuously transmitted real time data. The system 10 is anticipatory: it downlinks saved gap data when the satellite is confident it will successfully be received. (If that fails, the data will
10 still be retrieved at the next opportunity once the missing data is reported.)

Referring to Figure 4, if for some reason a segment of that open loop data never makes it successfully to the processing center PC when anticipated, it can be requested
15 for retransmission (automatically) by the SOC 100 logic.

Such a request would occur, for example, if a receptor was physically damaged in a storm, or lost it's source of electrical power. The coverage map is then updated for future use with that receptor removed and uplinked at the
20 next opportunity to the satellite to correct it's future contact profile assertions. (The center 100 has the same coverage map and knows when data should arrive.) Note that even though the system 10 is nominally a very simple open

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In the case of noisy data receipt, for perhaps a temporary reason such as a severe local storm at a receptor (e.g. "rain fade"), then the coverage map will still get updated as a precaution for further use, and that noisy data gets subsequently recovered, since the system 10 also gracefully and automatically recovers from both a temporary

compromise in a receptor's performance, as well as from prolonged permanent outages. Note that noisy data (beyond correction capabilities) can be short term ("bursty") in system 10, and the whole pass over a receptor is mostly
5 valid and saved, and only the noisy parts recouped as needed.

System 10 automatically recognizes and adjusts the coverage map when a new receptor is brought on line. There is no need to tell the system it has been added and to look
10 for it. Also note that receptor deployment and installation is remarkably easy: a contracted local technician simply unpacks the unit (in maybe two or three convenient pieces), secures the receptor stanchion in approximately the appropriate North/South orientation (via a magnetic compass
15 or handheld GPS unit), and squares it vertically with a bubble level. Once power is provided and network communication (fiber optics connection) is established by conventional commercial methods, installation is complete. This crude initial orientation is adequate, since the
20 receptor is initially commanded in a simple search pattern remotely from the operations center, pointing the receptor antenna generally in the direction at the right time when a known system 10 satellite will over fly. Since the system 10

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5 Any receptor misalignment is dialed in as a bias to it's
future pointing commands from the operations center. Since
the satellite (instant) location is very accurately known
from it's orbital elements, and the location of a receptor
is also accurately known and fixed (via a onetime GPS
10 handheld measurement), the precise pointing locii for all
satellite/receptor dynamic combinations is easily and
accurately calculated. There is no need for constant
"hunting" and handshaking for acquisition. The receptor is
simply told where and when to point, and passes along
15 whatever it receives.

At least three means of insuring data integrity
(successful and complete data receipt) are available and
implemented in system 10:

10 Traditional error detection/correction overhead bits embedded in the data stream right on the satellite. (The usual digital communications procedure).

By comparing a delayed (time-shifted) "checksum" (etc.) stream of each original data packet (embedded in the

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(temperature, wind conditions, humidity and others), or more complex such as automatic cloud cover assessment devices. A simple video camera and microphone at the receptor could also be handy for remote receptor health assessment.

5 A significant cost savings and simplification of the processing center ("PC") occurs when system 10 is used instead of a traditional ground station architecture. In a traditional system, data arrives at the processing center in bursts, as spacecraft in the constellation rapidly downlink to a station data collected during one orbit of the spacecraft around the earth. There are long quiet periods at the PC when the spacecraft are away from station coverage for prolonged stretches. Since these PC abrupt ingest bursts can be from any one of the spacecraft in a constellation, an obvious approach is to share the PC computing capacity among the various spacecraft for computing resource efficiency. However, there is substantial complexity and development cost associated with managing one large computer resource to service several different spacecraft simultaneously and asynchronously. In System 10, however, data arrives at the PC from all spacecraft more or less continuously, with the exception of brief receptor coverage gap zones. This makes practical a

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Referring to Figure 5, a processing center (PC) having the foregoing advantages may comprise two separate processors 110 and 112 which use the same type of hardware. They have identical but separate operating systems, and they execute different algorithms required for the processing of signals from different satellites. Processor 110 is dedicated to processing mission data received from satellite

5 lower capacity and lower cost than providing a single high
speed processor to process data for both satellite 20 and
satellite 22. In addition, each processor may be

10 When a new satellite comes on line, a new processor is added
and may be programmed to handle the data from the new
satellite. Since satellite systems advance rapidly in
capability, this technique ensures that the processing
center will not become obsolete when a new satellite begins
15 to feed data to the processing center. The existing
satellites and their respective computers may continue to
function. The new satellite can be brought on line by
merely programming a new computer to handle its needs while
the existing computers continue to function as in the past.

20 In summary, the preferred embodiment offers at least
the following advantages over the known traditional systems:

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- 1) Near-zero final weather product timeliness: continuous data from all satellites instead of bursts of large amounts of widely separated (in time) data bunches;
- 2) Robustness;
- 3) Growth and redundancy;
- 4) No orbital phasing control required; any initial phasing, any orbit drift is accommodated
- 5) Downlink bandwidth can be in the tens of Mbps;
- 6) "Preemption" concerns disappear; planned, random, pronounced, or permanent;
- 7) Unmanned (no human errors, training, housing, management);
- 8) Security issues and concerns eliminated or more easily controlled;
- 9) Life-Cycle-Cost reduction; more economical overall (inexpensive terminals, no staffing);
- 10) Spacecraft simplified, more reliable (no gimbaled antenna: fixed/shaped beam);
- 11) Can be an independent adjunct to "Traditional" ground stations (enhancement, backup);
- 12) No need to artificially crop physical contact opportunities (no minimum pass time imposed);

13) No S/C-to-Ground Station coordination, cooperation, scheduling (mostly gone);

14) Mix and match orbits (e.g. different missions, different altitudes/periods) (no competition for station
5 time);

15) Potential external funding since the system could be utilized by other future satellite systems;

sub a12 16) No concern about simultaneous downloads to same terminal (physically can't);

sub a13 17) Simple deployment and installation ;

sub a14 18) An excellent approach to system autonomy (Autonomous Mode).

Those skilled in the art will recognize that only the preferred embodiments of the invention have been described
15 in this specification. These embodiments may be modified and altered without departing from the true spirit and scope of the invention as defined in the accompanying claims.

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